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Technological Substitution In Transmission Facilities For Local Telecommunications

Lawrence K. Vanston, Ph.D.
Ralph C. Lenz

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Ameritech
Bell Atlantic Corporation
Bell Canada
BellSouth Corporation
Cincinnati Bell Telephone
Contel Corporation
GTE Service Corporation
NYNEX Corporation
Pacific Telesis
Southern New England Telephone
Southwestern Bell Corporation
U.S. West, Inc.

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Illinois Bell Telephone Co.
Indiana Bell Telephone Co., Inc.
Michigan Bell Telephone Co.
Ohio Bell Telephone Co.
Wisconsin Bell, Inc.

General Telephone Co. of California
General Telephone Co. of Florida
General Telephone Co. of the Northwest, Inc.
GTE Midwestern Telephone Operations
General Telephone Co. of the Southwest
General Telephone Co. of the South
Hawaiian Telephone (GTE)

Mountain Bell
Northwestern Bell
Pacific Northwest Bell Telephone Co.

Pacific Bell

New England Telephone & Telegraph Co.
New York Telephone Co.

South Central Bell Telephone Co.
Southern Bell Telephone Co.

Southwestern Bell Telephone Co.

Cincinnati Bell

Contel Corporation

Bell Canada

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TECHNOLOGICAL SUBSTITUTION IN TRANSMISSION FACILITIES FOR LOCAL TELECOMMUNICATIONS

EXECUTIVE SUMMARY

Revolutionary technological changes are having a profound impact on all operations of local exchange telecommunications companies. This study considers the impact of these changes on their outside plant, i.e., the cable and equipment on which messages and signals are transmitted between the subscriber and the central office (the subscriber outside plant), and between central offices (the interoffice outside plant).[1]

Traditionally, individual copper wire-pairs in cable have been the medium for the transmission of a message in the outside plant. However, because of recent improvements in digital technology, as well as in fiber optics, most interoffice circuits, and an increasing number of subscriber pairs, are now provided on carrier systems. Such systems eliminate or greatly reduce the amount of copper cable used for transmission. As forecast in the study, this trend away from copper cable will accelerate in response to technological and economic drivers and the demand for new services.

The timing of the demise of copper cable by digital carrier and fiber is important because copper cable is the bulk of the outside plant investment of more than $70 billion,[2] which must be depreciated before it is no longer economically useful. (Of this cable investment, the interoffice outside plant accounts for approximately 20%, subscriber feeder, 35%, and subscriber distribution, 45%.[3]) Depreciation issues aside, the rates of adoption of digital carrier and fiber optics are of particular interest to network and strategic planners.

Therefore, Technology Futures, Inc. was commissioned to develop forecasts of the timing of copper cable's demise and the adoption of digital carrier and fiber optics. The approach chosen was to predict the substitution of circuits on digital carrier and fiber optics for circuits on individual voice frequency copper pairs.[4] The study was sponsored by the Technology Forecasting Users Group which includes all seven of the regional Bell operating companies, the GTE telephone

1. The network architecture in use by local exchange carriers in the interoffice and subscriber (feeder and distribution) outside plant is discussed in Chapter Two.
2. Composite MA-16 reports for major U.S. local exchange carriers (December 31, 1986).
3. From Appendix D.
4. It is important to recognize that *substitution* is not synonymous with replacement. Physical retirements of copper cable might not occur in quantity until well after the beginning of the fiber substitution.

companies, Contel, Cincinnati Bell, Southern New England Telephone, and Bell Canada.

The forecasts are developed using the well-known Fisher-Pry model, described and referenced in the body of the report. This model has been shown to be applicable to both telecommunications and many other industries.[5,6] It holds that the substitution of a new technology for an old follows an S-shaped curve as shown in Exhibit ES.1. A particular substitution is characterized by its substitution rate, which is normally a constant throughout the substitution. The substitution rate, and thus the time span for the substitution, varies from one substitution to another, but the basic S-shape is common to most substitutions. Therefore, it has been shown that by using the substitution rate suggested by early data, we can project the remainder of a substitution to its conclusion.

Forecasted in this report are: (1) the substitution of derived circuits for non-derived circuits in the interoffice plant and (2) the substitution of derived subscriber pairs for non-derived subscriber pairs in the subscriber feeder plant. Derived circuits (or subscriber pairs) are those which are electronically derived by various multiplexing techniques, either analog or digital. Non-derived circuits (or subscriber pairs) provide a single conversation path on individual, voice frequency copper pairs. Also forecasted are the related substitutions of circuits (or subscriber pairs) on fiber optics for all types of circuits (or subscriber pairs) on metallic cable. Although the formal substitution analysis is limited to the interoffice outside plant and the feeder portion of the subscriber outside plant, probable scenarios are developed for the adoption of new technologies in the distribution portion of the outside plant.[7]

The progress of these substitutions is measured by the percentage of equivalent voice frequency circuits (or subscriber pairs) that are served by derived circuits on carrier systems. An equivalent voice frequency circuit has the ability to carry one normal two-way telephone conversation. These units were chosen because they accurately reflect the usefulness of each technology and because they have been tracked historically.

5. Ralph C. Lenz and Lawrence K. Vanston, *Comparisons of Technology Substitutions in Telecommunications and Other Industries* (Austin: Technology Futures, Inc., 1986). The Executive Summary is included here as Appendix F.
6. Kimbugwe A. Kateregga, *Technological Forecasting Models and Their Applications in Capital Recovery* (Department of Industrial Engineering, Iowa State University, 1986).
7. The forecasts for the interoffice and subscriber feeder outside plant are developed in Chapters Three and Four. The scenarios for the adoption of fiber optics in the subscriber distribution plant are discussed in Chapter Five.

The drivers of the substitutions are (1) continued technological progress and cost reductions in digital carrier electronics and fiber optics, (2) increased efficiency from synergies with digital switching and digital customer premises equipment, and (3) revenue opportunities from new business and residential services made possible by the new digital and fiber optics technologies.

To support the forecasting effort and to provide a comprehensive overview of technological trends in the outside plant, data were collected from 32 telephone companies. Together the U.S. companies covered in this report account for 85% of the access lines in the United States.[8] This may represent the largest collection of outside plant data ever compiled.

In 1987, 81% of the interoffice circuits in service, and 4.5% of the subscriber pairs used, were electronically derived rather than served by individual voice frequency copper pairs. By the end of 1989 the industry plans to have 86% derived circuits in the interoffice plant and almost 7% derived subscriber pairs in the subscriber feeder plant.

From the forecasts developed in the body of the report, it is likely that 99% of all interoffice circuits will be derived by 1995 and that the interoffice network will be essentially all fiber by 1999. The forecasts are less precise for the loop plant because the loop substitution has not progressed as far as the interoffice substitution. *However, we predict that, in the subscriber feeder plant, 99% of all subscriber pairs will be derived pairs during the period between 2004 and 2012, with a "most-likely" date of 2009.*

Exhibits ES.2 and ES.3 summarize the forecasts for the interoffice and subscriber feeder substitutions. Because of the effect of fiber optics, the phase-out of non-derived circuits will proceed faster than it would otherwise. Also, for the subscriber feeder plant, the substitution will proceed quite rapidly between 1993 and 2001. During this period, we predict that much of today's metallic feeder plant will be rendered obsolete.

The scenario for the adoption of fiber optics indicates that the network will be all fiber by the early 2020s. As shown in Exhibit ES.4, fiber to the subscriber is projected to successively penetrate market segments in the following order: field trials, large businesses, small businesses and new residences, wealthy residences, and finally other residences. This projection is based on (1) projected cost trends for fiber optics, digital electronics, and consumer electronics, (2) willingness to

8. Per *U.S. Industrial Outlook*, 99 million out of 117 million access lines in 1985.

pay by the market segments, and (3) economies of scale.

Exhibit ES.5 compares an earlier forecast on the substitution of digital for analog switching[9] to the forecasts developed here for the outside plant. The adoption of interoffice derived (mostly digital) circuits has historically led the adoption of digital switching. However, in the future, the switching and interoffice circuit substitutions will rapidly converge, until between 1997 and 2001 the interoffice network (including switching) will be all digital.

The switching and subscriber feeder substitutions were both at about 1% digital in 1983, but the switching substitution has proceeded at a faster pace since then. Referring again to Exhibit ES.5, we see that the lower bound subscriber feeder substitution parallels the lower bound switching substitution after 1995, lagging it by about seven years. The synergies between digital switching and both interoffice and subscriber digital circuits will likely drive the substitutions closer to the lower bound forecasts.

While the interoffice network will likely be all digital by the turn of the century, the feeder plant will still contain non-derived elements. However, by 2000 the feeder plant will most likely be over 70% derived (and digital). Further, most of the non-derived subscriber pairs remaining in 2000 will be serving customers close to the central office and therefore will be capable of providing digital services. Thus, the network will likely be all or almost all digital (and served largely by fiber feeder) by the year 2000.

The scenario for the penetration of fiber optics to the subscriber is shown by the right-most curve in Exhibit ES.5. The curve parallels the feeder substitution and lags it by about twelve years. The adoption of fiber to the subscriber implies the replacement of copper cable in both the feeder and distribution portions of the local loop. (However, fiber will already have replaced much of the copper cable in the feeder plant by the time significant amounts of fiber are extended to the subscriber.) If the scenario holds true, the demise of copper in the outside plant will be complete by the early 2020s.

The interoffice, subscriber feeder, and the previous digital switching forecasts are based on historical and planning data. They reflect the economic drivers that have historically driven these substitutions. These economic drivers will make both existing and new services more economical. The forecasts do not, however, fully reflect the future demand for new digital, broadband, or fiber services. Nor

9. Lenz and Vanston, *Comparisons of Technology Substitutions*, p. 69.

do they reflect the competitive forces that are emerging in the industry. Therefore, the forecasts are likely to underestimate the rate of substitution. They represent the minimum the industry needs to achieve to remain competitive.

EXHIBIT ES.1

THE FISHER-PRY MODEL

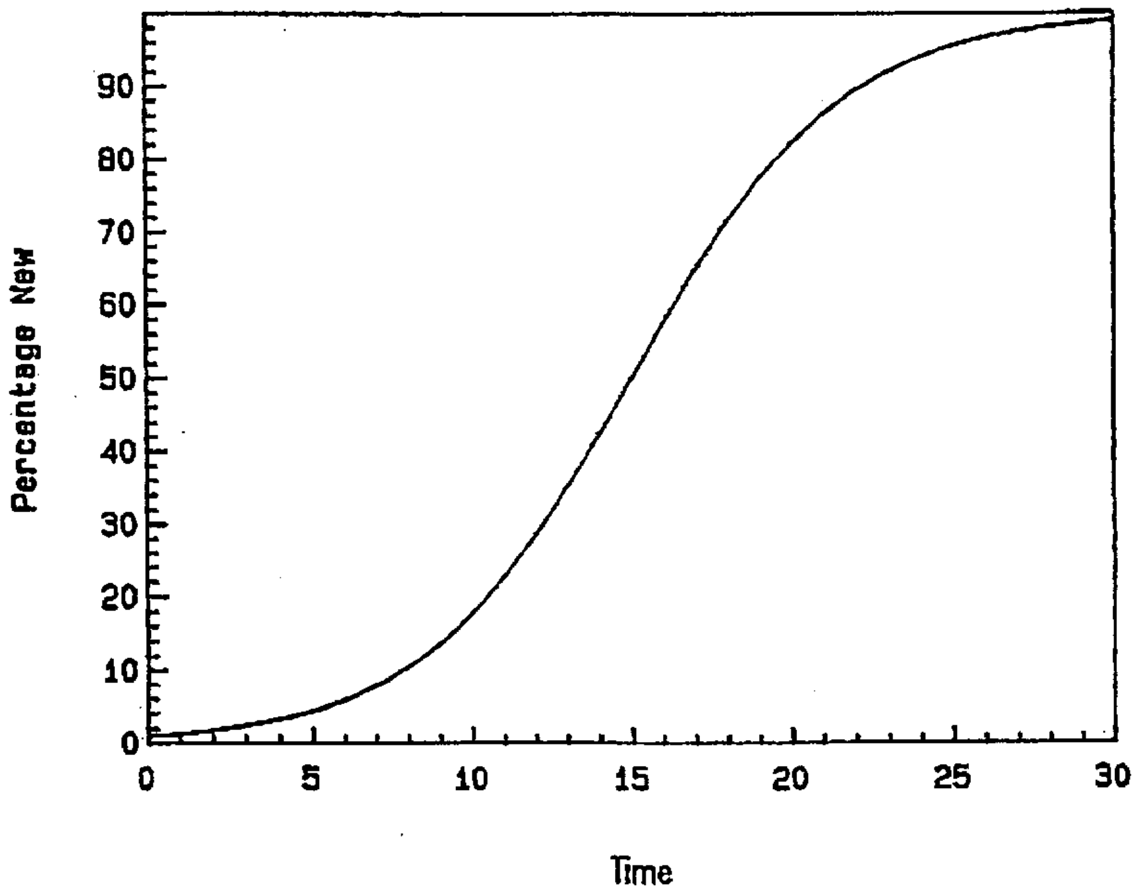


EXHIBIT ES.2

INTEROFFICE FORECASTS

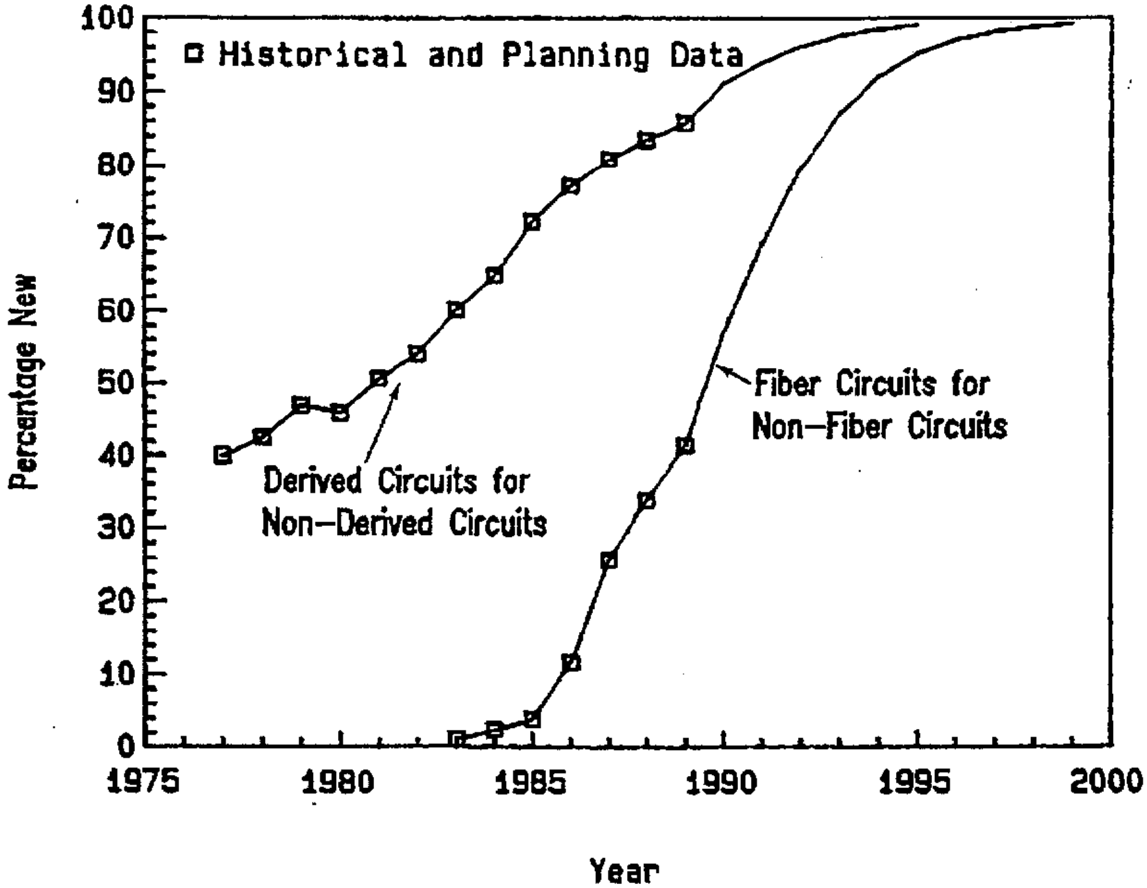


EXHIBIT ES.3

SUBSCRIBER FEEDER FORECASTS

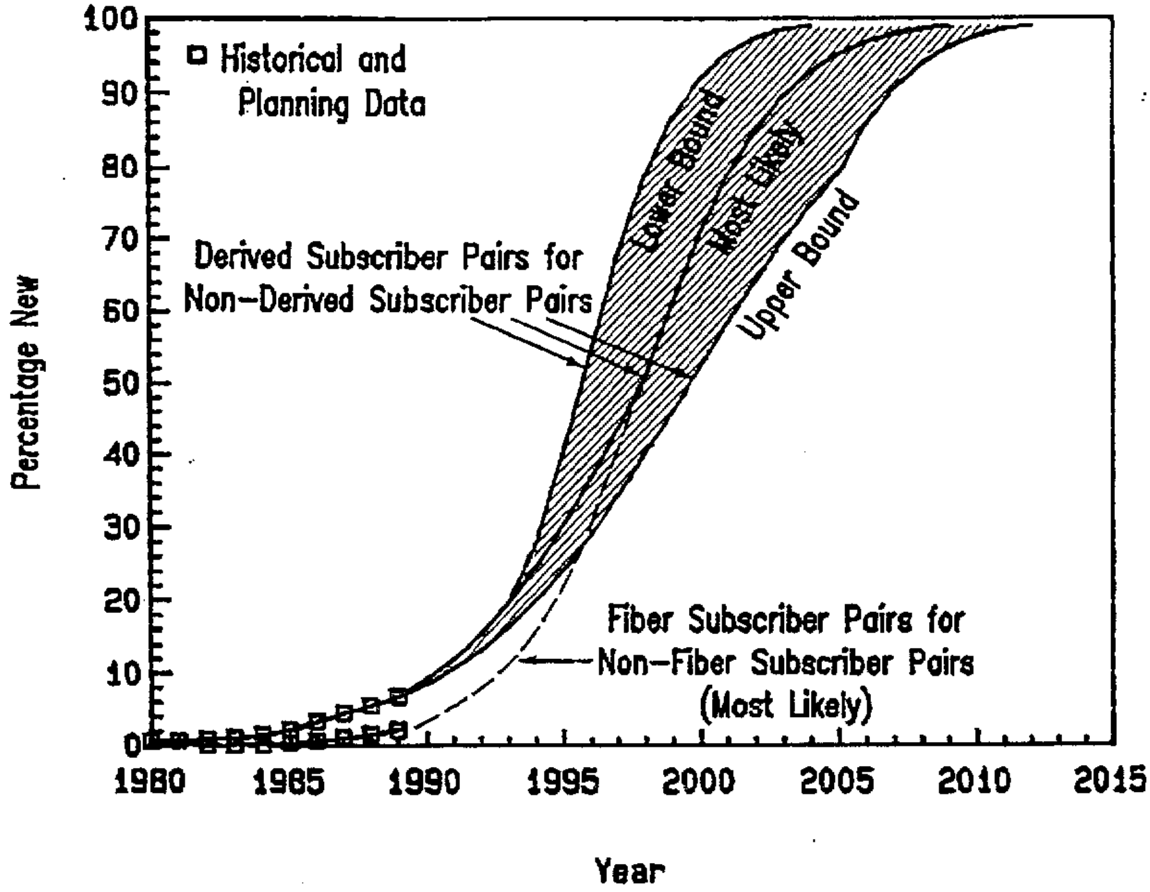
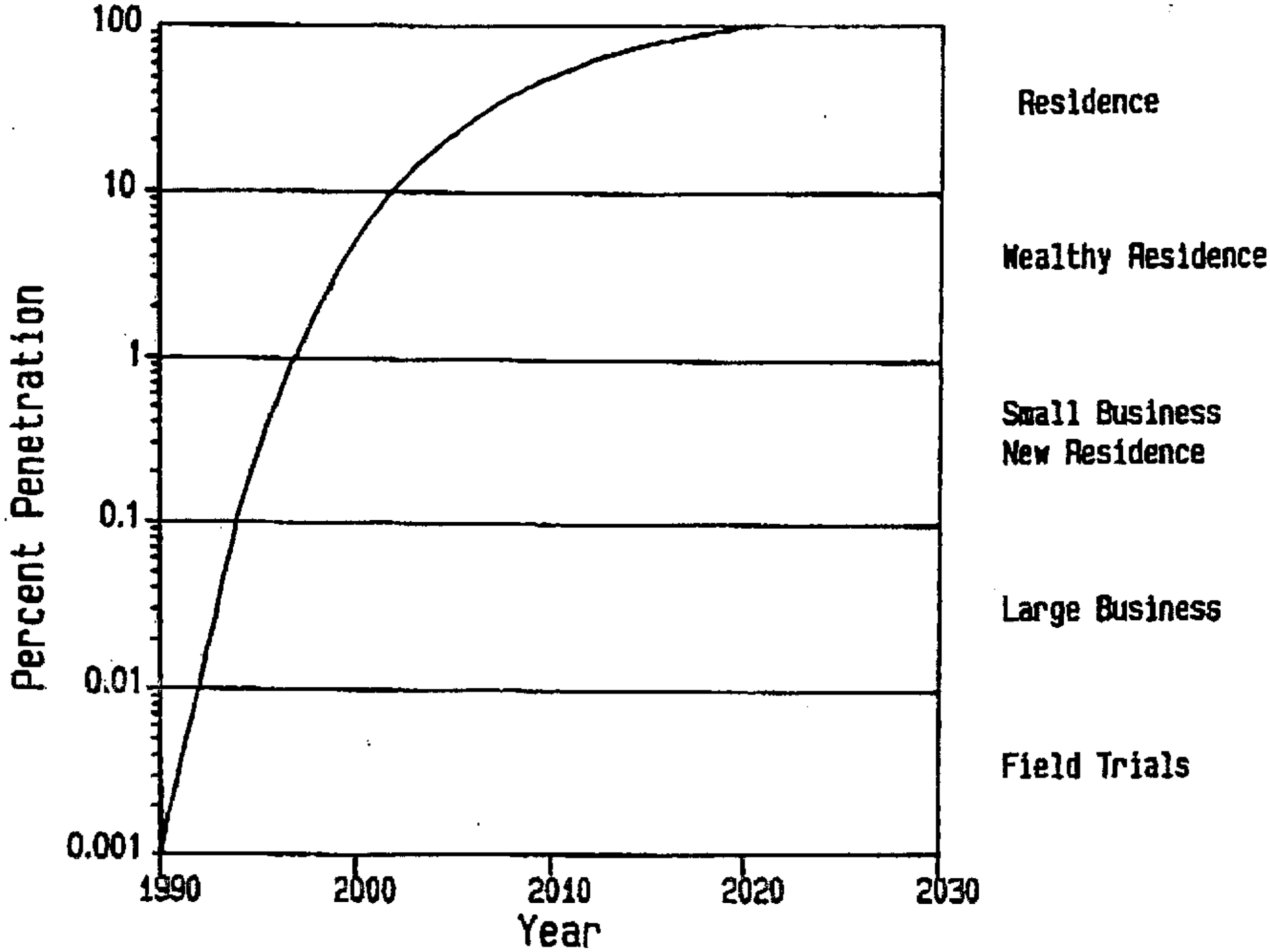


EXHIBIT ES.4

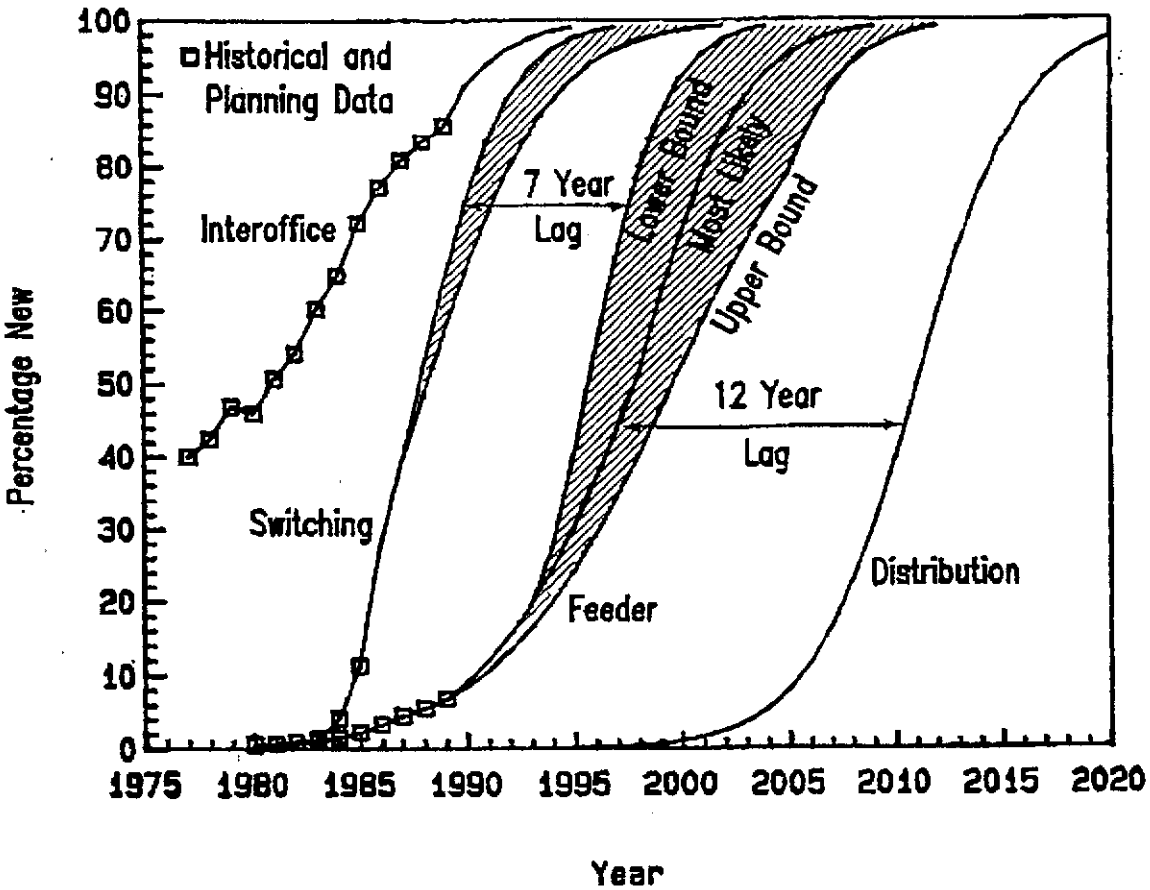
SCENARIO FOR THE PENETRATION OF FIBER TO THE SUBSCRIBER



Source: Bellcore

EXHIBIT ES.5

COMPARISON OF DIGITAL SWITCHING FOR ANALOG SWITCHING AND OUTSIDE PLANT SUBSTITUTIONS



Interoffice: Derived Circuits for Non–Derived Circuits
Switching: Digital for Analog Switching (Subscriber Lines)
Feeder: Derived Subscriber Pairs for Non–Derived Subscriber Pairs
Distribution: Fiber Subscriber Pairs for Copper Subscriber Pairs

serving area has well-defined geographic boundaries and subscribers within the area are served by distribution plant emanating from the remote electronics equipment location. This design has proven to be an economic and easily administered approach for serving subscribers with remote electronics. The introduction of fiber optics has resulted in fundamental changes in the CSA characteristics—the distance of the CSA from the central office is being reduced because the length of the central office to remote terminal feeder link is becoming a less significant factor.

Data obtained in this industry-wide study indicate that many of the operating companies that have adopted the CSA concept are planning to deploy fiber-fed remote terminals closer to the subscriber. Revised procedures typically call for maximum distribution distances in the 3,000 to 5,000 feet range, rather than the current value of 12,000 feet. This enables the operating company to provide high-capacity services through the fiber remote terminal rather than by separate, special, and dedicated facilities. This approach provides construction cost savings and greater operational efficiency.

Several of the reporting companies noted that these procedures are being introduced first in primary metropolitan centers, and will then be extended to wider regions as demand for high bandwidth service grows. The survey data also showed that the distance between the central office and the remote terminal is no longer a significant factor in determining whether fiber should be deployed but that, instead, bandwidth capacity is the driving criteria.

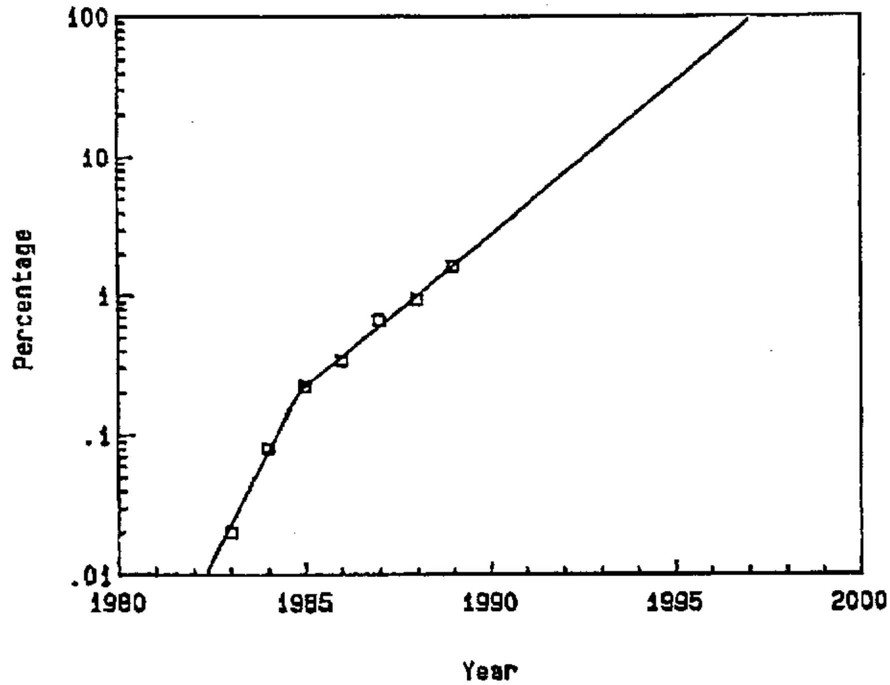
Fiber to the Subscriber. The use of fiber to serve subscribers directly, without any intervening metallic cable, is an emerging trend. Currently, this method of access is provided on a dedicated basis without intermediate cross-connection points. As discussed below, the long-term trend is toward broadband, all-fiber networks. These initial instances of all-fiber access loops indicate how demand for broadband connectivity may develop and directions for network evolution.

Exhibit 5.3 shows survey results for the percentage of "fiber only" subscriber pairs growing with time. While fewer than 1% of the total installed pair capacity is offered on all-fiber facilities overall, the number of operating companies providing fiber access has been steadily increasing. The first reported instance of all-fiber loops occurred in 1980. By 1984, the number of reporting companies deploying all-fiber access had grown to seven. Survey data demonstrates that these installations are primarily in metropolitan areas for large business subscribers. The principal applications are broadband special services, such as

1.5 Mb/s or 45 Mb/s digital links that can be used for aggregated voice traffic from PBXs or high-speed data communications. Projection of the trend in Exhibit 5.3 suggests that the use of all-fiber loops will extend to greater than 5% of overall loop pair capacity by 1992. This estimate may be conservative, however, as the demand for high-capacity all-fiber loops will be stimulated by the emergence of new services which require high bandwidth.

EXHIBIT 5.3

FIBER ONLY PAIRS AS A PERCENTAGE OF TOTAL SUBSCRIBER PAIRS



Source: Responses to supplemental data form. See Appendix D.

By this timeframe, it is quite probable that a high level of demand for high-quality video services will have evolved, together with both a consumer product market and an extensive variety of sources. Initial technical demonstrations of high-definition video has aroused considerable attention, as the picture quality is distinctly superior to today's broadcast or cable networks. The combination of fiber optics and integrated electronics is the enabling element to this new service capability, and the demand may be the stimulation necessary for widespread deployment of a broadband network.

2005 TIMEFRAME

By the early twenty-first century, deployment of fiber in the subscriber plant should be occurring at a rapid rate, with a substantial fraction of a fiber-based distribution network in place. The results of this industry-wide study given in Chapter Three indicate that within this timeframe the interoffice network will be entirely fiber. Chapter Four shows that fiber will be used extensively in the feeder as well. Several scenarios for broadband deployment have been suggested, and even the more conservative estimates (often based on the pattern of CATV penetration in the U.S.) show a substantial presence of fiber to the subscriber in this timeframe. Underlying forces contributing to the deployment include decreased cost due to volume production, the firm establishment of digital video standards, and the development of new information and entertainment services.

A progressive scenario for broadband evolution is provided in Exhibit 5.7. This model assumes a somewhat more aggressive penetration of fiber than the CATV pattern would suggest. This is driven by the already demonstrated demand for broadband services in the business sector. By the mid-1990s, the business demand will have led to the deployment of infrastructure in the metropolitan areas, and migration of the broadband network into the residential sector then proceeds incrementally. For CATV, such incremental growth was not achieved, as the systems were deployed separately, without sharing of common elements. By satisfying business demand first, a substantial user base will be established, permitting volume production of subscriber elements facilitating the consequent economy of scale.

These trends are summarized in Exhibit 5.8, which shows each of the phases of broadband implementation. The figures suggest the steady growth in subscriber lines together with the decreased cost per line. By the early 21st century, new construction and a significant portion of the small business and residence sectors will have been reached by fiber. This network will support a broad spectrum of services, ranging from very low bit rate telemetry for meter reading, security, and energy management, through conventional voice and high-fidelity audio, and including a variety of video formats and capabilities. Integrated access, as suggested early in the prototype research, will be commonplace. All duplicate access facilities, such as copper pair or coaxial, will be obsolete.

EXHIBIT 5.7

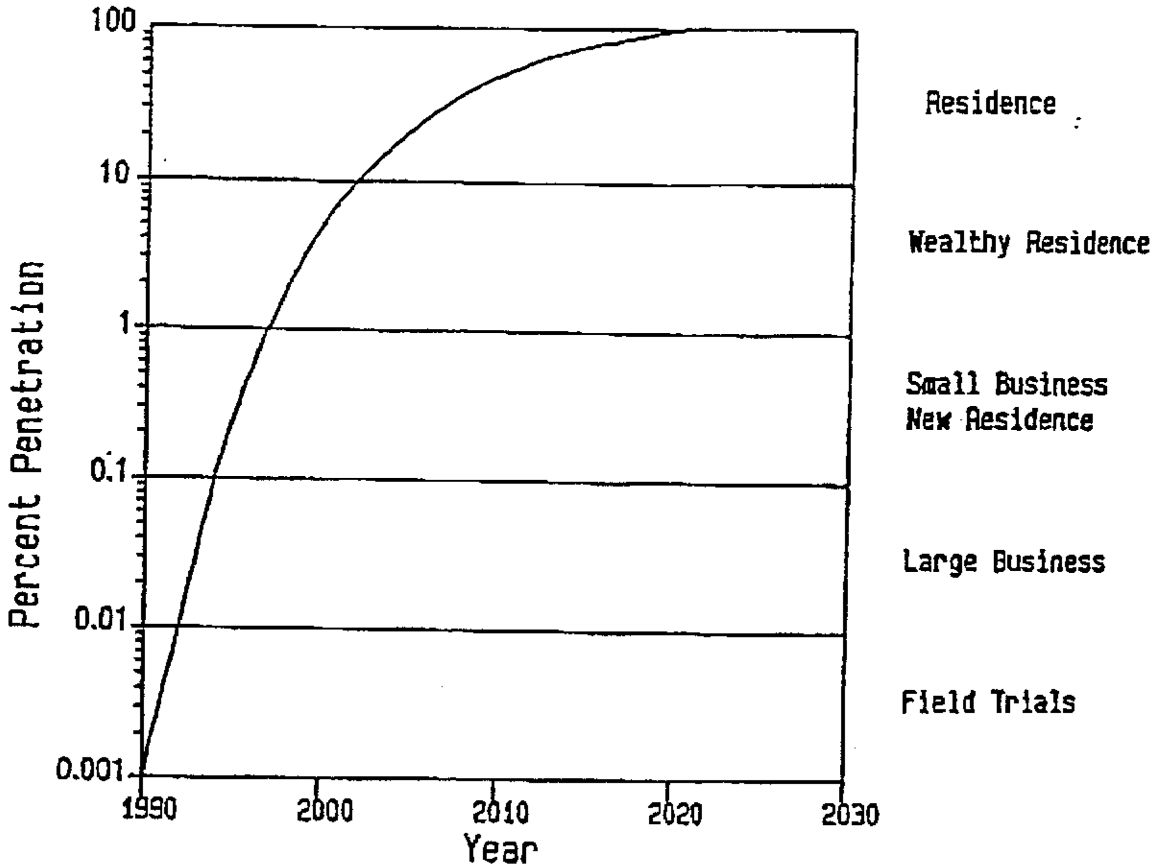
PROGRESSIVE BISDN DEVELOPMENT PENETRATION AND COST ESTIMATES

Phase	Duration (Years)	Final Size %	Final Size Lines	Lines/ Year	Cost/ Line	$/Line	Monthly Revenue
Field Trials 1990-1992	2	0.01	15K		Po	$20K	$500
Large Business 1992-1997	5	1	1.5M	300K	Po/4	$5K	125
Small Business New Residence 1997-2002	5	10	15M	2.5M	Po/9	$2.2K	60
Wealthy Residence 2002-2007	5	20	30M	3M	Po/12	$1.7K	43
Residence 2007-2022	15	100	150M	8M	Po/12	$1.7K	43

Source: Bellcore

EXHIBIT 5.8

BISDN PROGRESSIVE DEPLOYMENT



Source: Bellcore